LCA Case Studies

Energy Analysis of Solar Water Heating Systems in India

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Abstract

This analysis can be called energy accounting of solar water heating systems. Five types of solar water heating systems have been considered. With the help of material balance, energy content has been found in these systems. Yearly output of systems has been found by conducting transient simulations using hourly data of radiation and ambient temperature. Such analysis has been done separately for one representative city of each of six climatic zones of India. The energy payback for India ranges from 0.73 to 4.16 years for the thirty cases considered here.

Keywords: Climatic zones; energy analysis; energy payback; evacuated tube collector; flat plate collector; solar water heating systems

1 Introduction

As per the International Federation of Institutes for advanced studies (IFIAS), the term energy analysis means 'the determination of the energy sequestered in the process of making a good or service within the framework of an agreed set of conventions or applying the information so obtained' [1]. The total energy sequestered is called 'Energy Content' which, in itself, includes all the energy inputs either direct or indirect. Broadly, energy inputs are clubbed under two major heads, namely, energy inputs as materials and energy input in manufacturing processes. When added together the final value is also termed as the cumulated energy demand of the system. This value may be used for various purposes. Such an analysis has been done for photovoltaic systems in India [2], but since solar water heating is the most popular form of solar energy utilisation in India and has a wide acceptance in commercial as well as in the domestic sector it is justified to compare various types of such systems in different climatic conditions. Since in India, there is a wide variation in the climatic conditions from one end to its other end, the classification of India into six climatic zones, done by Bansal and Minke [3] has been adopted. One representative city of each climatic zone has been considered in this analysis. Five basic types of collectors have been considered in this analysis, the details of which are as follows:

Type I: Single glazed, flat plate collector with black paint on absorber

Type II: Single glazed, flat plate collector with selective coating on absorber

Type III: Double glazed, flat plate collector with black paint on absorber

Type IV: Double glazed, flat plate collector with selective coating on absorber

Type V: Evacuated tube collector

2 System Details

For the reason of comparison of various types of solar water heating systems, the basic skeleton has been kept the same for all five types. The following parameters are common to all the categories considered here:

- collector area: 2 sq. meter
- hot water tank capacity: 100 lt
- cold water tank capacity: 1000 lt
- 100 mm thick EPS insulation for hot-water tank
- 30 mm thick insulation for hot-water pipes
- 0.5 mm thick aluminium cover for insulation
- 16 SWG M.S. sheet for hot-water tank
- 1" angle iron for supporting frame for hot-water tank
- cold water tank placed on masonry support
- (latitude +15) degree inclination of the collector

2.1 Flat plate collector (FPC)

The basic structure of FPC consists of an absorber plate which absorbs heat and transfers it to the tubes attached to it that carry water inside [4]. By absorbing solar energy, water becomes hot and its density is reduced. The upwards density gradient thus created causes water to flow, this phenomenon is called thermosyphon. Some configurations include a fluid pump to maintain flow, are called forced sys-

tems. But in this analysis only the thermosyphon system has been considered. Top of the collector box is covered with a glass cover which allows solar radiation to pass through and prevents thermal radiation to go back when emitted by the absorber. The number of glazings may be one or two, more is the number of glazing less radiation will reach the absorber but at the same time offering more resistance to the heat loss to the surroundings. Thus it is evident that different types of collectors will give different energy output at the same location. The collector specifications considered were based on the recommendations of the 'Bureau of Indian Standards'. Main parameters of the collector are as follows:

- Absorber plate: 30 SWG copper
- Risers: 12.7 mm Diameter, 0.7 mm. thick copper
- Thickness of glazing: 4.0 mm
- Aluminium sheet for collector: 1 mm. thick for box, 0.5 mm for insulation cover
- Insulation: 50 mm thick EPS in bottom and 30 mm. in sides of collector box
- Aluminium frame for collector box: 1" angle, 1.2 mm thick
- Supporting frame: 1/ 2" angle iron for single glazed, 1" for double glazed

2.2 Evacuated tube collector (ETC)

The working principle of the ETC is different from that of FPC. In ETC, unlike FPC, the absorber is split in a number of length-wise segments, each separately encapsulated in a vacuumised glass tube to minimise convection and conduction loss to the atmosphere. By absorbing heat from the incident solar radiation, water or any low boiling fluid gets evaporated and the vapours thus formed rise upwards, where the vapour heat is extracted for utilisation via condensation. The condensate flows back to the absorber tubes for recirculation. Besides the advantage of enhanced collection, this system consumes less material as compared to FPC. Following are the ETC system parameters taken during this analysis:

- Absorber plate: 30 SWG copper
- Fluid tubes: 12.7 mm Diameter, 0.7 mm thick copper
- Tube fins: 30 SWG copper
- Vacuum: 10 mbar
- Glass tubes: 10 tubes of 80 mm diam. in 2 sq. meter
- Length of hot water pipe: 2 meter
- Supporting frame: 1/2" angle iron

3 Engergy Content

The energy content of solar water heating systems has been calculated primarily on the basis of the physical dimensions. **Table 1** shows the specific energy contents of various materials used in FPC and ETC. GEMIS [6] has been used as the reference for the specific energy contents, however, some modifications have been done wherever found necessary to suit the Indian case according to the degree of recycling, the electricity mix and efficiency of energy utilisation in Indian industries. Multiplication of this figure with the weight of material used gave the energy content which has been shown in **Table 2.** It clearly shows that the energy content of type I & II is 5.79 GJ and that of type III & IV is 6.53 GJ, against 3.77 GJ for type V.

Table 1: Specific energy contents for different parts of solar water heating systems

Part name	Components	Material	Specific Energy Content (MJ/Kg)
Collector	Absorber Risers Glazing Insulation Tray	Copper Copper Glass EPS Aluminium	94.82 94.82 14.00 96.20 261.9
Storage tank	Shell Insulation Insulation cover	Mild steel EPS Aluminium	27.27 96.20 261.9
Piping	Pipe Insulation Insulation cover	Galvanised iron EPS Aluminium	27.27 96.20 261.9
Support frame	Frame	Angle iron	27.27
Cold-water tank	Tank	Plastic	101.4

Some energy is also used in the manufacturing processes required to make such systems. The main operations are:

- Welding for making hot-water tank
- Welding for making supporting frame
- Brazing of copper tubes with absorber
- Vacuumisation of tubes in ETC
- Mechanical joints made for other assembly operations

Data for energy consumed in welding, brazing and vacuumisation is based on actual measurements and represents the typical Indian case of these processes. Energy consumed in welding is 53.1 MJ for type I, III & V and 68 MJ for type II

Table 2: Energy contents of FPC and ETC Systems

Material	Single glazed FPC		Double glazed FPC		ETC	
	Weight (Kg)	Energy content (MJ)	Weight (Kg)	Energy content (MJ)	Weight (Kg)	Energy content (MJ)
Copper	10.5	995.6	10.5	995.6	8.0	758.56
Glass	22.0	308.0	44	616.0	20.0	280.00
Iron	24.5	668.1	30	818.1	24.5	668.11
EPS	11.7	1125.54	13.2	1269.84	5.7	548.34
Aluminium	7.6	1990.44	8.1	2121.39	3.1	811.89
Plastic	7.0	709.80	7.0	709.80	7.0	709.80
Total	**83.3**	**5797.38**	**112.8**	**6530.73**	**68.3**	**3776.7**

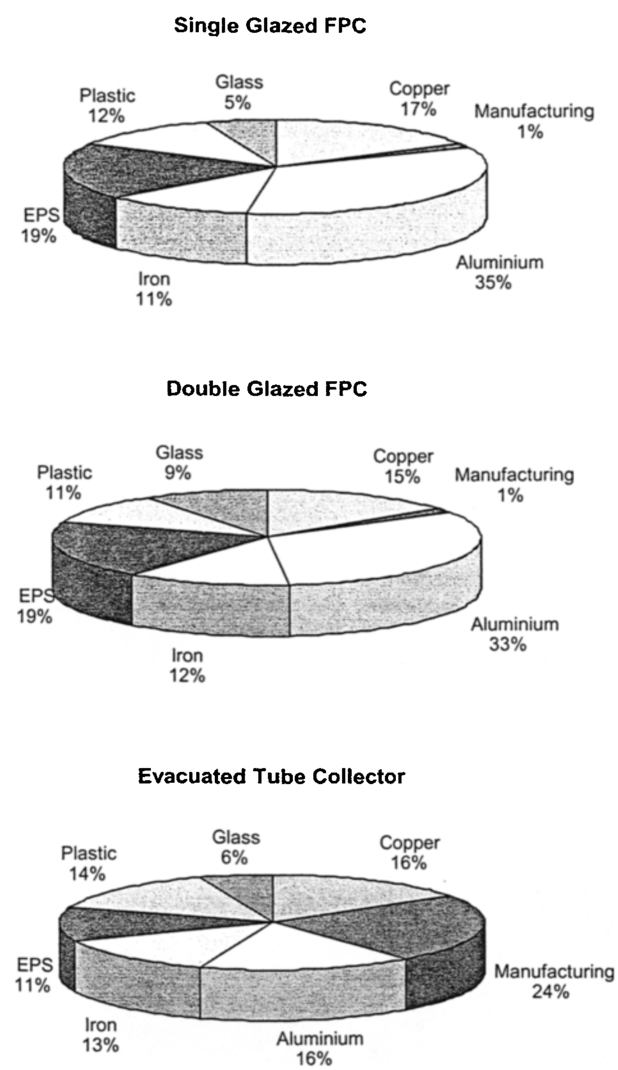

Fig. 1: Break-up of cumulated energy content of FPC and ETC Systems

& IV. Brazing energy is the same for all types as the length of brazing is equal. This value is 85.85 MJ. The energy consumed in creating a vacuum for ETC is 1065 MJ. Therefore, the total energy content of type I & III becomes 5.883 GJ, type II & IV becomes 6.619 GJ and that of type V, 4.928 GJ. These values have been arrived at on the basis of 10 trials for each process performed by the authors. Energy consumption for vacuumisation could also be calculated using standard nomograms [5]. The contribution of various materials and processes in total energy content is shown in the pi charts of **Figure 1**.

4 Energy Output

The energy collected by solar water heating systems depends upon the ambient conditions. Peculiar phase lag between maximum radiation and maximum temperature and a non-linear relationship between losses and ambient temperature make a transient analysis necessary for the correct estimation of energy collected. For this purpose, a software 'TRNSYS13' was used. It is a transient simulation software which works on a modular approach. The modular structure is useful in having a flexibility in taking output in any desirable form by adding separately written programs to it.

To meet the requirement of the modular structure of TRNSYS13, hourly data of radiation and temperature obtained from Indian Meteorological Department, New Delhi, was used. The climatic zones, their representative cities with annual radiation and annual mean temperature (in degrees Centigrade) that have been used in this analysis have been mentioned in Table 3.

The energy collected has been found by taking the sensible heating of 100 l. water as output at the end of each day for the whole year by writing a programme for TRNSYS13. The output was taken for the requirement of auxiliary energy for heating water up to 100 degrees Centrigrade and the difference of the total heat required and auxiliary heat

Table 3: Climatic data for different climatic zones of India

Climate	Rep. City	Annual Radiation	Mean Temp.
Hot & dry	Ahmedabad	9.89 GJ	28.0
Moderate	Bangalore	9.23 GJ	23.6
Composite	Delhi	9.12 GJ	25.3
Cold & sunny	Leh	6.22 GJ	5.50
Warm & humid	Madras	9.83 GJ	28.6
Cool & cloudy	Srinagar	8.88 GJ	13.4

required gave the collected energy of each day. The sum of this value for 365 days gave the annual energy collected. Table 4 shows the energy collected by all five types of collectors in the six cities.

Table 4: Energy collected in six cities of India (in GJ/year)

City	Type I	Type II	Type III	Type IV	Type V
Ahmedabad	4.73	4.98	4.49	4.83	6.73
Bangalore	4.31	4.54	4.08	4.41	5.84
Delhi	4.32	4.56	4.17	4.44	5.99
Leh	1.54	1.58	1.59	1.63	1.89
Madras	4.67	4.86	4.40	4.71	6.23
Srinagar	4.19	4.41	3.85	4.26	4.97

5 Energy Payback

The pay back period for different types of collectors in different climatic zones has been shown in Table 5. Despite the same energy content of Type I & III and Type II & IV their pay back periods are different as their outputs are different.

Table 5: Payback period (yrs.) of different types of systems in six cities of India

Rep. City	Type I	Type II	Type III	Type IV	Type V
Ahmedabad	1.24	1.18	1.47	1.37	0.73
Bangalore	1.36	1.29	1.62	1.50	0.84
Delhi	1.36	1.29	1.59	1.49	0.82
Leh	3.81	3.72	4.16	4.06	2.60
Madras	1.26	1.21	1.50	1.40	0.79
Srinagar	1.40	1.33	1.72	1.55	0.99

6 Conclusions

The analysis of solar water heating has revealed that the evacuated tube collector system has about 16% less energy content than single glazed and 26% less energy content than double glazed flat plate collectors. Due to reduced losses, it also delivers 20-30% more output than all other types in different climatic conditions considered in this analysis. The payback period is nearly one year for the system having evacuated tube collector as compared to about 1.5 years for other types, for all the stations other than Leh. Leh has relatively higher payback, but the evacuated tube type has the least payback period in such climate also. This suggests that the use of the evacuated type collector system should be promoted irrespective of the climatic conditions. Among the flat plate collectors, a single glazed collector with selective coating is the most suitable for Indian climatic conditions. The above analysis has purposely not been extended to find the energy yield ratio as the expected lifetime of different solar water heating systems may be different and reliable information regarding their lifetime in various climatic zones of India was not available to the authors. However, considering an average lifetime of the considered systems to be 15 years in India gives the energy yield ratio ranging from 3.60 for the system having a double glazed collector with black paint in Leh to 20.47 for a system with an evacuated tube collector in Ahmedabad.

7 References

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Erratum

Linear Programming as a Tool in Life Cycle Assessment
Adisa Azapagic, Roland Clift

Vol. 3, No. 6, p. 308, Eq. 11
Please note the correct reproduction of Eq. 11 below:

$$B_j = \sum_{c=1}^{C} \lambda_{j,c} e_c$$